National Aeronautics and Space Administration

Advanced Exploration Systems

NASA Advisory Council

November 15, 2012

Topics

- Program Status
- FY12 Accomplishments
- Innovation & Outreach
- FY13 Plans
- Coordination with Space Technology Program

Background

In FY12, Exploration Technology Development (ETD) was transferred from HEOMD to STP.

- ETD work was incorporated into two Space Technology Programs:
  - Game Changing Development (GCD) and
  - Technology Demonstration Missions (TDM)

- System-level integration work and prototype / design development for future exploration architecture elements remained in the HEOMD Advanced Exploration Systems (AES) Program.

ETD and AES Objectives

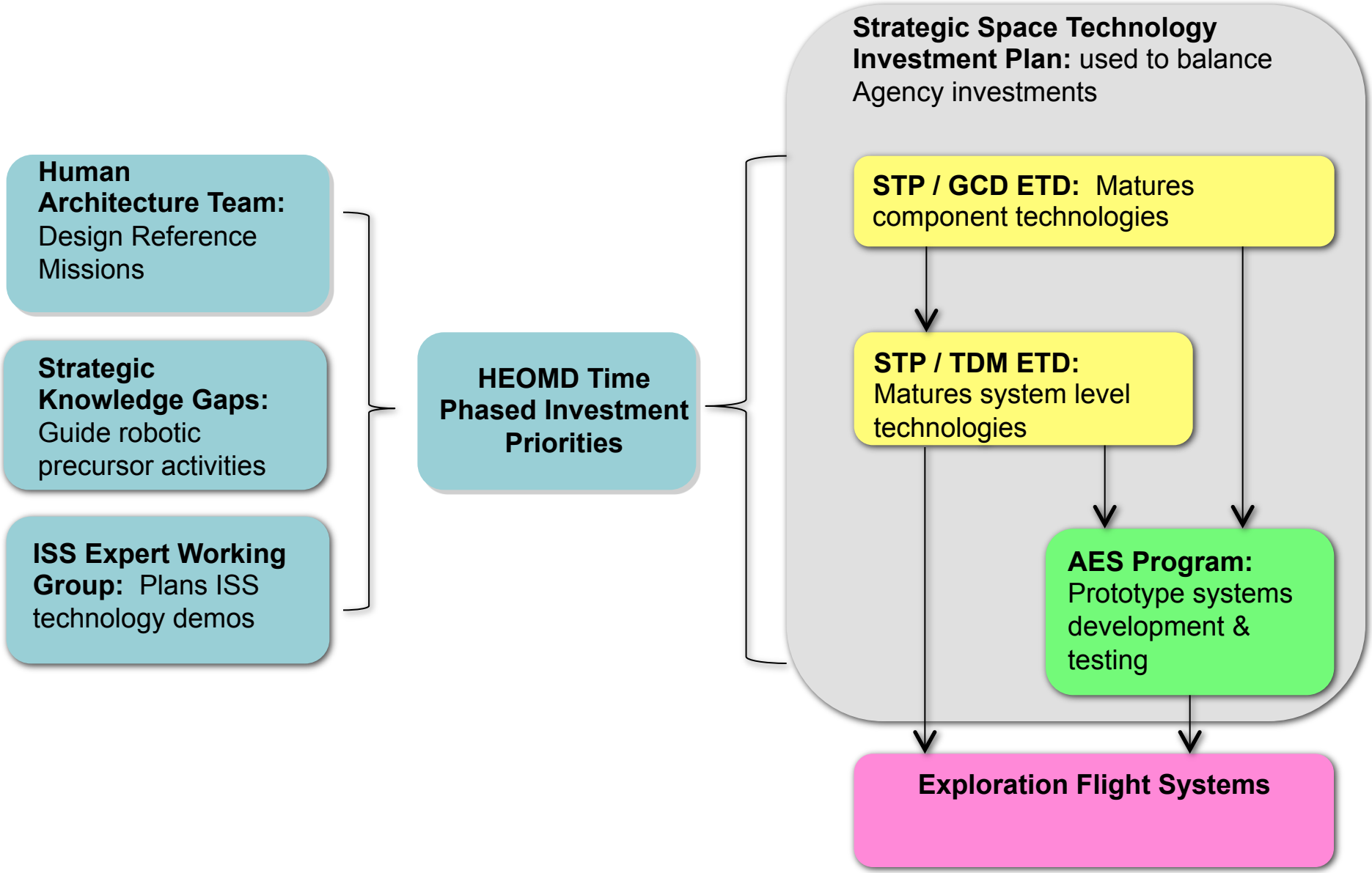
Exploration Technology Development (STP)

- Develop long-range foundational technologies and components to support human exploration needs.
- Conduct flight demonstration missions of high-priority exploration capabilities such as cryogenic propellant storage and solar electric propulsion.
- Mature technologies for infusion into mission-level programs and agency initiatives.
- Leverage synergies with game-changing and crosscutting technologies to support multiple customers and mission applications.

Advanced Exploration Systems (HEOMD)

- Advanced development of exploration systems to reduce risk, lower lifecycle cost, and validate operational concepts for future human missions beyond Earth orbit.
- Demonstrate prototype systems in ground test beds, field tests, underwater tests, and ISS flight experiments.
- Use and pioneer innovative approaches for affordable rapid systems development and provide hands-on experience for the NASA workforce.
- Maintain critical competencies at the NASA Centers and provide NASA personnel with opportunities to learn new and transform skills.
- Infuse new technologies developed by STP / ETD into exploration missions.
- Support robotic missions of opportunity to characterize potential destinations for human exploration.

Defining the Combined AES/STP Portfolio



Advanced Exploration Systems

Rapid development and testing of prototype systems and validation of operational concepts to reduce risk and cost of future exploration missions:

- **Crew Mobility Systems**
  - Systems to enable the crew to conduct “hands-on” surface exploration and in-space operations, including crew excursion vehicles, advanced space suits, and crew egress
- **Deep Space Habitation Systems**
  - Systems to enable the crew to live and work safely in deep space, including deep space habitats, reliable life support, radiation protection, and fire safety
- **Vehicle Systems**
  - Systems for in-space propulsion stages and small robotic landers, including nuclear propulsion, modular power systems, lander technology test beds, and autonomous precision landing
- **Operations**
  - Systems to enable more efficient mission and ground operations, including integrated testing, autonomous mission ops, integrated ground ops, and logistics reduction
- **Robotic Precursor Activities**
  - Acquire strategic knowledge on potential destinations for human exploration to inform systems development, including prospecting for lunar ice, characterizing the Mars surface radiation environment, radar imaging of NEAs, instrument development, and research and analysis

AES Program Status

- The AES Continuation Review was held at KSC on September 18-20. The purpose of this review was to assess the progress of the projects in achieving their FY12 milestones, and to review plans for FY13. AES completed 49 of 56 major milestones in FY12 (88%).

- Planning to redirect several AES projects in FY13 to support near term cis-lunar missions (i.e. EM1 and EM2 enhancing).

- Signed MOU with SMD for Joint Robotic Precursor Activities.

- A baseline set of Strategic Knowledge Gaps (SKGs) to guide the planning of robotic precursor missions has been reviewed by the LEAG, MEPAG, and SBAG. The SKGs will be incorporated into the next version of the Global Exploration Roadmap.

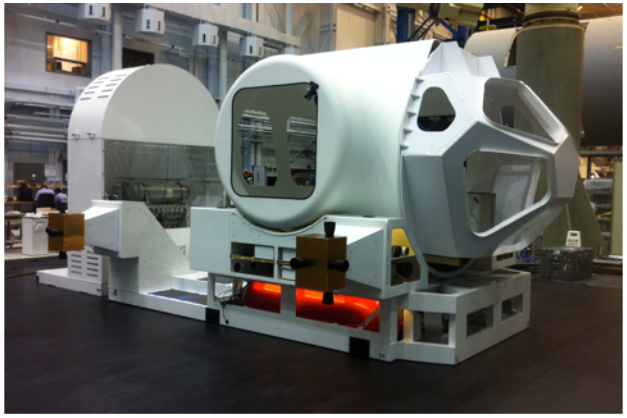
- Established flight project planning office at ARC to manage the RESOLVE lunar ice prospecting mission.

- The Morpheus test failure investigation concluded that hardware along the IMU data path (IMU or 1553 bus) failed due to excessive vibration levels at liftoff. Two new landers are being assembled, and flight tests will resume in early 2013. The new lander will include a higher thrust engine, vibration isolation, a redundant IMU, and additional 1553 data bus channel.

- ALHAT is planning to conduct a helicopter flight test of the hazard detection system in December at KSC.

FY12 Accomplishments

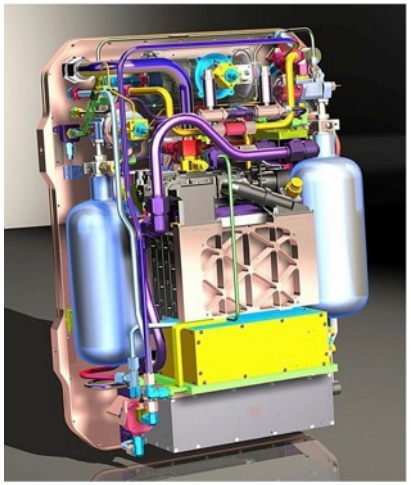
Crew Mobility Systems Domain



MMSEV: Evaluated habitability and mobility during tests on air bearing floor

EVA: Assessed mobility of Z-1 space suit in partial gravity aircraft flight tests.

Suitport: Conducted differential pressure tests of two suitport concepts with Z-1 spacesuit.



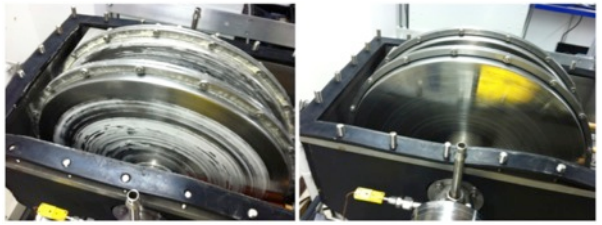
EVA: Designed prototype Portable Life Support System for advanced spacesuit.

FY12 Accomplishments

Deep Space Habitation Systems Domain

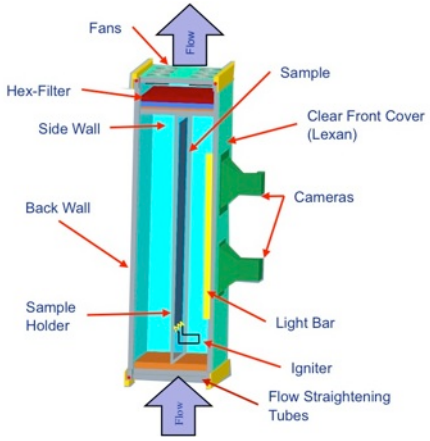
Habitat Systems: Developed crew accommodation concepts for Deep Space Habitat

Life Support (Air): Began integrated chamber testing of ISS-based air revitalization and environmental monitoring systems



Life Support (Water): Tested electrodialysis metathesis system to remove calcium from urine.

Logistics Reduction: Demonstrated Heat Melt Compactor for processing trash



Spacecraft Fire Safety: Defined large-scale fire experiment concept for flight on Cygnus vehicle

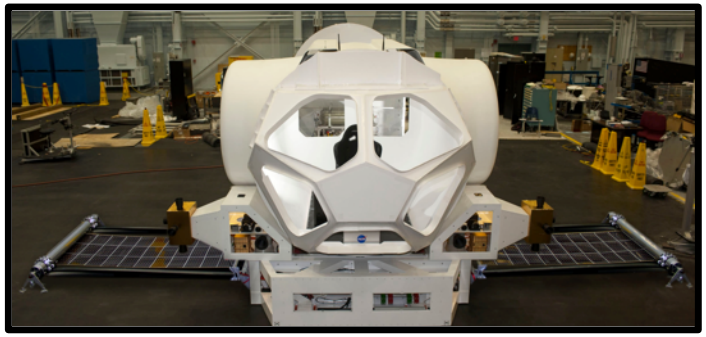
Radiation Protection: Demonstrated miniature radiation environment monitor and storm shelter concepts

FY12 Accomplishments

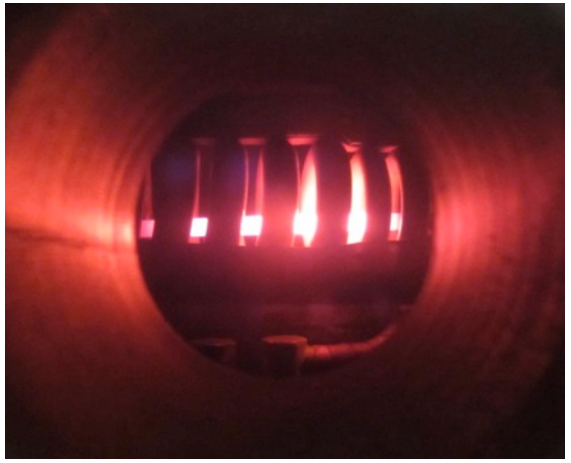
Vehicle Systems Domain

Morpheus Vertical Test Bed: Completed 20 tethered flight tests of Morpheus lander. New lander is being assembled to recover from test failure.

ALHAT: Integrated autonomous landing and hazard avoidance system hardware and software with Morpheus lander.



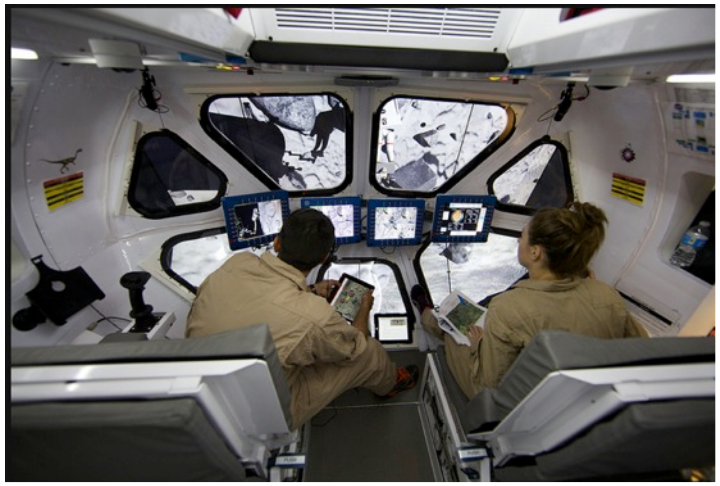
Modular Power Systems: Integrated roll-out solar arrays and fuel cell with MMSEV



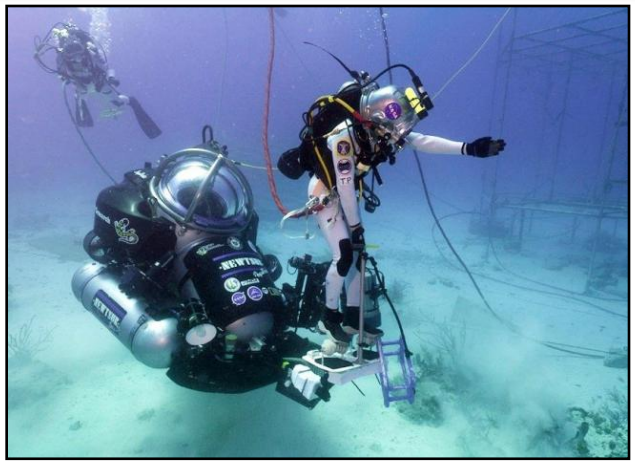
Nuclear Propulsion: Tested reactor fuel elements in hot hydrogen

FY12 Accomplishments

Operations Domain



Analog Missions: Simulated asteroid exploration mission with MMSEV and virtual reality



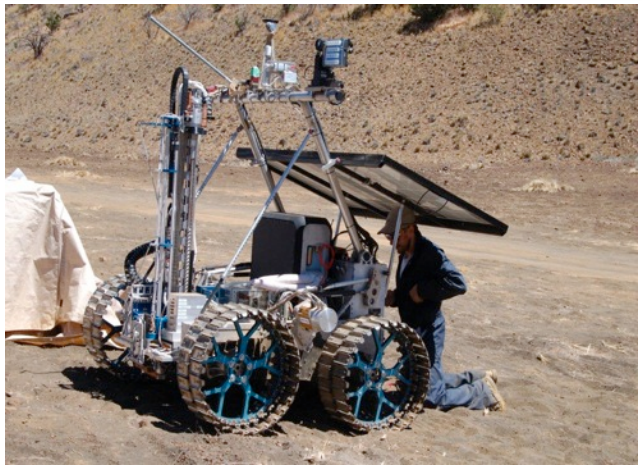
Analog Missions: Simulated asteroid exploration mission operations with communications time delay in NEEMO 16 underwater test

Autonomous Mission Operations: Demonstrated software tools for autonomous mission ops with communications time delay in Deep Space Habitat

Integrated Ground Ops: Assembled LOX propellant storage and handling system for autonomous propellant loading demonstration

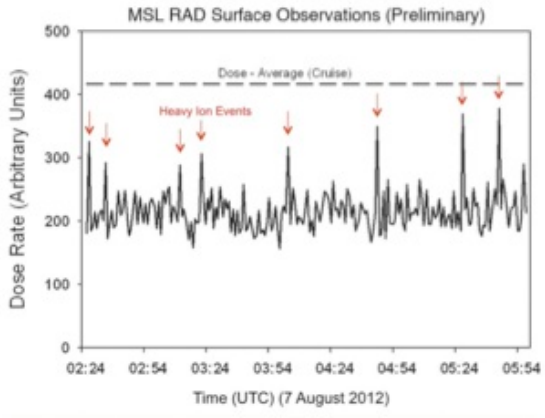
FY12 Accomplishments

Robotic Precursor Activities Domain

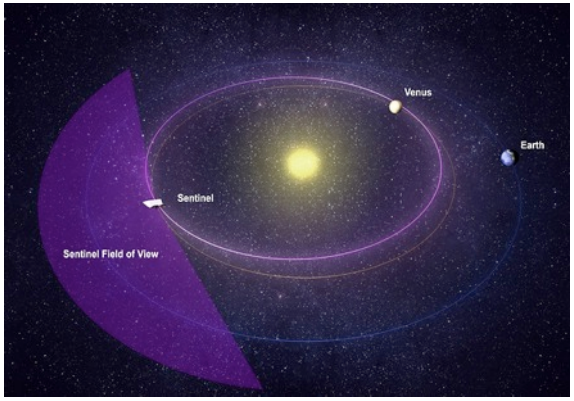


RESOLVE: Conducted field test in Hawaii of lunar ice prospecting experiment in partnership with Canadian Space Agency.

Goldstone Radar: Imaged 12 near-Earth asteroids to determine their orbits, size, shape, and spin rate.



Radiation Assessment Detector: Acquired radiation data during MSL's interplanetary cruise and on surface of Mars



Sentinel: NASA signed MOU with B612 Foundation to provide support for privately-funded Sentinel mission to detect near-Earth asteroids.

Project Success Criteria Reflect AES Program Objectives

AES Objectives	Project Success Criteria
Rapid development and demonstration of prototype systems	• Did the project complete its annual milestones?
Pioneer innovative approaches to improve affordability	• Did the project implement innovative approaches to improve affordability?
Create opportunities for the NASA workforce to gain hands-on experience and learn new skills	• Was most of the work performed in-house by civil servants instead of being outsourced to contractors? • Did people learn new skills?
Multi-disciplinary, highly-collaborative project teams working across organizational lines	• Did the project interact with other AES projects? • Did the project involve multiple NASA centers?
Infuse new technologies and capabilities into exploration missions	• Did the project incorporate new technologies? • Has the project identified a customer or end user? (ISS, Orion, SLS, JRPA)
Leverage partnerships to amplify investments	• Did the project establish partnerships with external organizations or other NASA programs?
Outreach	• Did the project engage the public through outreach activities?

Project Milestone Status

Project	Status
Autonomous Mission Ops	Completed communications time delay tests with HDU
Spacecraft Fire Safety	Replanning to reduce cost and to fly on OSC Cygnus vehicle
Modular Power Systems	Integrated roll-out solar array and fuel cell with MMSEV
Goldstone Radar Imaging of NEOs	Imaged 16 near-Earth asteroids; integrated new digital receiver
Radiation Assessment Detector	Acquired data during MSL cruise and on surface of Mars
Morpheus Lander	Vehicle destroyed in test failure; new lander is being built
ALHAT	Autonomous precision landing demo delayed due to Morpheus test failure
Analog Missions	Completed NEEMO 16 and ISRU field tests
MMSEV	Evaluated habitability and mobility on air bearing floor
EVA	Completed PLSS 2.0 design review

Project	Status
Suitport	Completed manned differential pressure test of suitport
Deep Space Hab	Completed integrated systems testing
Water Recovery	Testing commercial EDM unit to process urine
Air Resource Recovery & Environmental Monitoring	Started integrated test of ISS air revitalization components
Radiation Protection	Completed SRR for radiation monitor to fly on EFT-1 mission.
Logistics Reduction	Testing Heat Melt Compactor
Integrated Ground Ops	Tested LOX loading operations
RESOLVE	Completed field test in Hawaii.
Nuclear CPS	Tested fuel elements in hot hydrogen
Lunar Mapping & Modeling	Completed delivery of all products.

AES Pioneers Innovative Approaches for Affordably Developing New Capabilities

- AES projects follow a “skunkworks-like” model for rapid development of prototype systems. Project teams are multi-disciplinary, highly collaborative, and work across organizational lines. Teams consist primarily of NASA personnel, and most of the work is performed in house.

- AES maintains critical competencies at the NASA Centers, and provides NASA personnel with opportunities to learn new skills and gain hands-on experience.

- AES leverages partnerships with external organizations to amplify investments. Partnerships include ESA for spacecraft fire safety, CSA for in-situ resource utilization, CERN for radiation sensors, and DOE for nuclear propulsion.

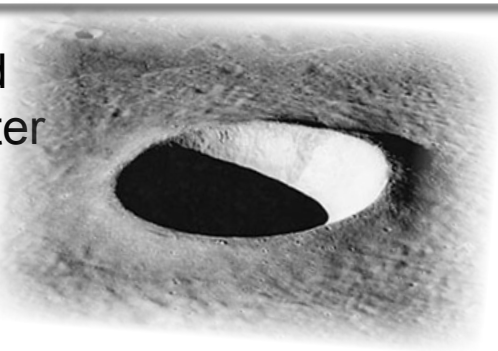
- Through NASA’s Center of Excellence for Collaborative Innovation (COECI), AES explores new models for problem solving using open innovation and crowd sourcing.
  - The NASA Tournament Lab sponsors competitions to engage the public in developing software to solve NASA challenges.
  - The COECI is working with OSTP to implement collaborative innovation across the Government.

NASA Tournament Lab

- Operational Virtual Facility developed between NASA, Harvard, and TopCoder
- Two Objectives –
  - Create novel, high quality working software for NASA algorithmic / computational Challenges by engaging public *("crowdsourcing" or distributed innovation)*
  - Contribute towards the development of empirically validated science of distributed innovation tournaments

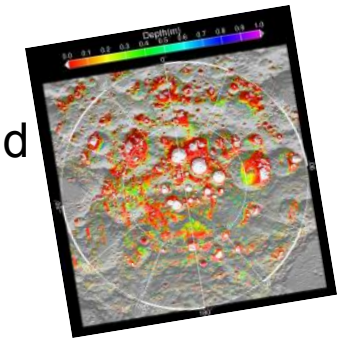
- Outcome: Utilizes the principles of distributed innovation enable participants worldwide to contribute to solving mission challenges by developing innovative computational algorithms

Automated Lunar Crater Detection



Vehicle Recognition for Pipeline threats

Planetary Data Accessibility and Applications



Robonaut Tasking and movement

ISS Longeron shadowing for Visiting vehicles

CubeSat Launch Initiative

- Universities and other Non-Profits use SmallSats as a means to:
  - Provide meaningful aerospace and STEM education
  - Advance the development of technologies (SBIR, Space Grant)
  - Conduct Scientific Research
- CubeSats provide cost-effective platform for development, but launch opportunities have historically been limited and unreliable
- NASA's CubeSat Launch initiative (CSLI) provides opportunities for CubeSat payloads to fly on rockets planned for upcoming launches.
  - Flown as auxiliary payloads on previously planned missions.
  - CubeSat investigations should be consistent with NASA's Strategic Plan and the Education Strategic Coordination Framework. The research should address aspects of science, exploration, technology development, education or operations.

Call #	Call Date	Notify Date	# Responses	# Recommended
1	2/23/2010	8/2/2010	16	12
2	7/30/2010	1/31/2011	32	20
3	8/5/2011	2/10/2012	43	32
Total	---	---	91	64

University Involvement in the AES Program

- Over the last 3 years, the Exploration Habitat (X-Hab) Academic Innovation Challenge has selected 12 university teams to develop concepts and technologies for the AES Deep Space Habitat project.
- Over 25 universities are collaborating with AES projects to develop radiation protection, life support systems, logistics reduction technologies, and nuclear thermal propulsion.
- 60 students have worked at JSC on the Morpheus lander
- The NASA Lunar Science Institute funds 4 university-led teams to conduct research on the moon and small bodies to address both exploration and science objectives.

University of Wisconsin students developed an inflatable loft for NASA's Habitat Demonstration Unit

Strategy for FY13 Planning

- Refocus several existing projects to support crewed missions in cis-lunar space in this decade.
- Start new crosscutting projects that consolidate similar elements from existing AES projects
- Continue activities that are extensible to multiple destinations in the longer term.

Changes to Existing Projects in FY13

- **Habitat Systems**
  - Develop deep space habitat design based on MPLM class module.
  - Begin integration of life support, power, avionics, and other key systems in deep space habitat habitat ground test unit

- **Life Support Systems**
  - Develop concepts for deep space habitat and habitable airlock life support systems
  - Continue integrated ground testing of ISS-derived ECLSS components
  - Begin system integration with deep space habitat ground test unit
  - Support ECLSS technology demonstrations on ISS

- **Multi-Mission Space Exploration Vehicle**
  - Defer plans to develop crew excursion vehicle for NEA exploration
  - Focus on developing habitable airlock/node for deep space habitat

- **Suitport**
  - No immediate need for suitports to support cis-lunar exploration
  - Complete suitport pressure testing, then stop further development.

Changes to Existing Projects in FY13

- **Morpheus/ALHAT**
  - Combine Morpheus and ALHAT into single project.
  - Rebuild Morpheus lander with higher thrust HD5 engine.
  - Complete ALHAT flight tests at KSC.
  - Issue RFI to seek models for potential industry involvement to develop lunar lander for RESOLVE mission.

  RESOLVE
  - Focus on risk reduction looking forward to a potential flight mission in 2017.
  - Defer Vacuum Development Unit; same objective can be achieved in thermal vacuum testing of flight hardware

- **Analogs**
  - Defer testing of operational concepts for MMSEV and NEA missions
  - Focus on integrated systems testing to support deep space habitat activities

- **Autonomous Mission Ops**
  - Develop autonomous systems to tend deep space habitat when the crew is not present.

New Projects in FY13

- **Additive Manufacturing**: Demonstrate fabrication of spare parts on ISS using 3D printing. Jointly funded by AES, ISS, and STP.
- **Bigelow Expandable Activity Module**: Test of commercially-developed inflatable module on ISS.
- **Common Avionics:** Crosscutting project to develop common avionics components and architectures for exploration systems.
- **Core Flight Software**: Crosscutting project to develop core flight software for exploration systems.
- **Delay Tolerant Networking**: Demonstrating protocols and technologies to enable efficient and reliable space communications.
- **Ka-Band Objects Observation & Monitoring**: Phased antenna array to detect orbiting objects and near-Earth asteroids.

Major FY13 AES Milestones

November 2012	**Spacecraft Fire Safety**: Conduct Mission Concept Review and Systems Requirements Review
January 2013	**Radiation Protection**: Complete the Critical Design Review for the EFT-1 Radiation Environment Monitor
March 2013	**Bigelow Expandable Activity Module**: Complete Phase 1 Safety Review
April 2013	**Deep Space Habitat:** Complete Systems Definition Review for MPLM-based deep space habitat
June 2013	**Morpheus/ALHAT**: Complete KSC flight tests of ALHAT on Morpheus lander to demonstrate autonomous hazard detection and avoidance.
July 2013	**EVA**: Complete assembly and integrated testing of Portable Life Support System 2.0 to validate schematic and packaging concept.
August 2013	**RESOLVE**: Develop integrated schedule and project plan for lunar ice prospecting mission and complete Mission Concept Review.

Approved list of 63 AES Program level FY13 Milestones signed in October 2012

HEOMD - AES / STP - ETD Coordination Approach

- **Both programs are aligned with the highest priority technology needs identified in mission architecture studies**.
  - The Human Architecture Team (HAT) and Strategic Knowledge Gaps are used to create a integrated set of time phased technology priorities and design reference mission concepts to both ETD and AES

- **Several AES and ETD projects are integrally linked to foster collaboration and provide a direct technology infusion path.**
  - STP / ETD projects focus on the development of component technologies (GCD – e.g. HRS) as well as the demonstration of system level technology capabilities (TDM – e.g. CPST)
  - AES projects integrate mature technologies from ETD and perform design and prototyping of future exploration systems.
  - STP has developed a “Mission Use Agreement” document that specifies the technology infusion path (including requirements, milestones, resources).

- **Frequent coordination ensure tight linkages between the programs are appropriately managed**.
  - AES participates in STP project formulation and status meetings.
  - STP is involved in the selection of AES projects and attends AES program reviews.
  - HEOMD is a member of the STP Program Management Council in which program status and key decisions are discussed.
  - Regular leadership meetings occur between AES management and STP management
  - NASA Technology Executive Council (NTEC), chaired by Agency Chief Technologist, coordinates technology investments across the Agency

STP Exploration Technology Development Portfolio

- **The ETD portfolio develops component technologies (GCD) and demonstrates system level technologies (TDM) for exploration:**
  - Robotic Systems
    - Human Exploration Telerobotics (TDM)
    - Human-Robotic Systems (GCD)
  - Space Power and Propulsion
    - Cryogenic Propellant Storage & Transfer (TDM)
    - Solar Electric Propulsion (GCD)
    - Solar Array Systems (GCD)
    - Space Propulsion (GCD)
    - Green Propellant (TDM)
    - Space Power Generation & Storage (GCD)
    - Nuclear Power Systems (GCD)
  - Crew Support Systems
    - Advanced Radiation Analysis Tools (GCD)
    - Next Generation Life Support (GCD)
  - In-Situ Resource Utilization (GCD)
  - Autonomous Systems (GCD)
  - Entry, Descent, and Landing
    - Hypersonic Inflatable Aerodynamic Decelerators (GCD)
    - Deployable Aeroshell Concepts (GCD)
    - MEDLI (TDM)
    - ALHAT (TDM)
  - Structures and Materials
    - Composite Cryogenic Propellant Tank (GCD)
    - Materials International Space Station Experiment-X (TDM)
    - Lightweight Materials & Structures (GCD)

Critical Areas with AES Collaboration
Critical Areas only covered by ETD

STP Deliveries to AES

2012 2013 2014 2015 2016 2017 2018 2019

SLS / MPCV

- Woven TPS for Orion heat shield compression pads
- Composite Cryogenic Tank for Upper Stage

SEV

- 1kW Fuel Cell for Modular Power Sys
- MCCAD radiation modeling
- Grappling & Dexterous Arms
- Composite cabin

EVA

- Rapid Cycle Amine (RCA) for PLSS
- Jetpack
- EVA Glove
- Variable Oxygen Reg (VOR) for PLSS

DSH

- Alt Water Processor
- Hab Automation S/W

Mission Ops

- Autonomous Cryogenic Loading Ops

Robotic Precursors

- Ballistic Cannon & Rover for NEA
- GC-Mass Spec for RESOLVE
- Neutron Spec for RESOLVE

In-Space Propulsion

- 13kW Hall thruster & 170V class PPU
- Cryogenic Propellant Storage & Transfer Demo
- Solar Array Systems for SEP

Status of STP Technology Infusion into AES

STP Project	Technology Products	AES Projects targeted for infusion	Status
Advanced Radiation Protection	Solar particle event forecast models, radiation transport models	Radiation Protection	STP addresses areas not covered by AES. AES is developing dosimetry sensors and radiation shielding
Autonomous Precision Landing (ALHAT)	ALHAT system integration and testing	Morpheus/ALHAT	ALHAT has been integrated with Morpheus lander
Autonomous Systems	Autonomous software for Deep Space Hab and cryogenic propellant loading	Autonomous Mission Ops, Integrated Ground Ops	Significant overlap with AMO and Integrated Ground Ops project objectives
Next Generation Life Support	Rapid Cycle Amine system to remove CO2, Variable Oxygen Pressure Regulator	EVA	Products delivered for integration into EVA suit portable life support system
Human Robotic Systems	Manipulator arms, EVA jet packs	MMSEV	On track for delivery
In-Situ Resource Utilization	Near infrared and neutron spectrometers for characterizing lunar resources	RESOLVE	On track for delivery
Space Power Generation & Storage	EVA battery, non-flow through fuel cells	Modular Power Systems	AES milestone missed due to late delivery of 1 kW fuel cell

Summary

- AES completed 49 of 56 major project milestones in FY12 (88%).
- AES pioneers innovation through NASA Tournament Lab, Cubesat Launch Initiative, and student involvement.
- The AES portfolio is being realigned in FY13 to support crewed missions in cis-lunar space in this decade.
- STP and AES are closely coupled to mature and infuse new technologies into exploration missions.
- By leveraging synergies with game-changing and crosscutting technologies in STP, Exploration Technology Development supports multiple NASA mission applications.
- Regular, periodic coordination and review of STP and AES activities ensures activities and developments are coordinated and complementary.